

**Close out and Final report for  
NASA Glenn Cooperative Agreement NCC3-865**

**Adaptive Development**

**Introduction**

The goal of this research is to develop and demonstrate innovative adaptive seal technologies that can lead to dramatic improvements in engine performance, life, range, and emissions, and enhance operability for next generation gas turbine engines.

This work is concentrated on the development of self-adaptive clearance control systems for gas turbine engines. Researchers have targeted the high-pressure turbine (HPT) blade tip seal location for following reasons:

- Current active clearance control (ACC) systems (e.g., thermal case-cooling schemes) cannot respond to blade tip clearance changes due to mechanical, thermal, and aerodynamic loads. As such they are prone to wear due to the required tight running clearances during operation.
- Blade tip seal wear (increased clearances) reduces engine efficiency, performance, and service life.
- Adaptive sealing technology research has inherent impact on all envisioned 21st century propulsion systems (e.g. distributed vectored, hybrid and electric drive propulsion concepts).

*Benefits of the Technology*

Adaptive sealing technology has far reaching benefits to numerous rotating machinery markets including aerospace, power generation, chemical processing, refinery, etc. Specific benefits of the technology as applied to HPT blade tip sealing of today's commercial aircraft include:

- **Specific fuel consumption (SFC):** SFC savings between 1 and 1.5%. A 1% SFC savings applied over the fleet would save \$160M/yr in 2002 and is projected to \$240M/yr in 2025.<sup>1,2</sup>
- **Emissions:** A 1% lower fuel burn applied across the fleet would reduce total aircraft volatile organic compound (VOC) emissions up to 4 million pounds per year and NOx by 3 million pounds per year.<sup>1,3</sup>
- **Life:** Preventing HPT clearance growth over time dramatically slows the growth of engine exhaust gas temperature (EGT). When an engine reaches its FAA certified EGT limit the engine must be pulled from the wing and serviced. Applying an advanced ACC

system enabled by the proposed research would significantly increase engine life (time on wing). The servicing of today's large commercial engines can easily exceed \$1M.<sup>1</sup>

## **Research and Technical Objectives**

The primary objectives for the first and second years of this three-year proposal were to develop and fabricate a mechanical ACC system and a test rig in which to evaluate the design. The test rig was to simulate the shroud-seal environment of a large commercial gas turbine engine. The ACC system was to function in this environment under proper thermal and pressure loads, while achieving the positioning rate and accuracy required to obtain the benefits of a mechanical ACC system.

## **Responsibilities of Principal Investigator**

As Principle Investigator of this research, Dr. Lattime is responsible for developing new seal concepts and approaches for demonstrating their performance. He is expected to perform technical analysis and feasibility assessments, both analytically and experimentally, on developed concepts and provide direction for his research based on these assessments. Dr. Lattime is responsible for overseeing the direction and progress of outside contractors, consultants, grantees, students, etc. assigned to assist him in this work. His duties also include reporting results in both written and oral formats to the NASA Technical Monitor, staff, management and customers as well as publishing technical reports/journal articles and presenting research at technical conferences. Dr. Lattime is also expected to prepare technical proposals and budgets for the funding of his research.

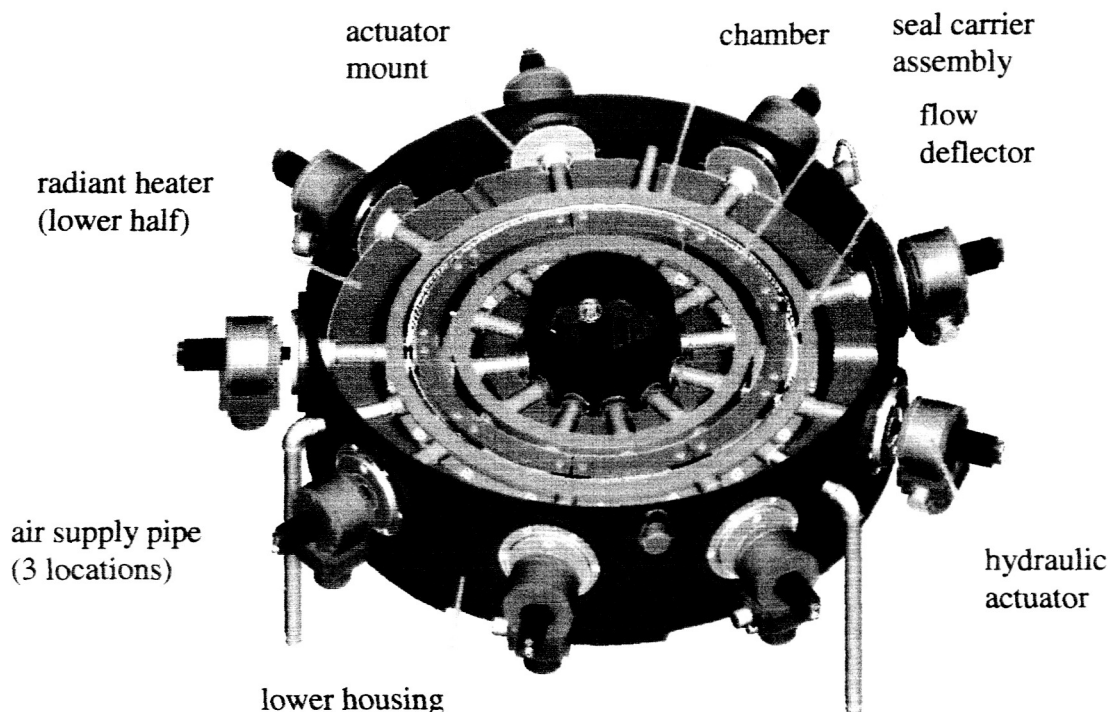
## **Achievements**

### ***FY03***

*Completed Design of First Generation ACC System Concept and ACC Test Rig:* A mechanically actuated ACC system concept was designed. The concept is based on a segmented shroud whose segments are radially positioned via mechanical linkages connected to actuators that reside outside the extreme environment of the HPT. Researchers opted for this design due to a lack of high temperature/low profile actuators that are presently available. The system was designed to operate up to 1,500 °F, under a 150 psig pressure load, and achieve 0.2-in total radial stroke, at 0.04-in/s, and a positional accuracy of less than 0.004-in.<sup>4</sup>

A state-of-the-art test rig was designed to evaluate the ACC system concept under simulated HPT temperatures and pressures. The test rig housing and main components are shown in Figures 1 through 3. Figures 1 and 2 show the inside of the housing and the major components of the rig. The test rig comprises six main components: the housing, the radiant heater, the pressurized chamber, the seal carrier assembly, the actuator rod assemblies, and the hydraulic actuators.

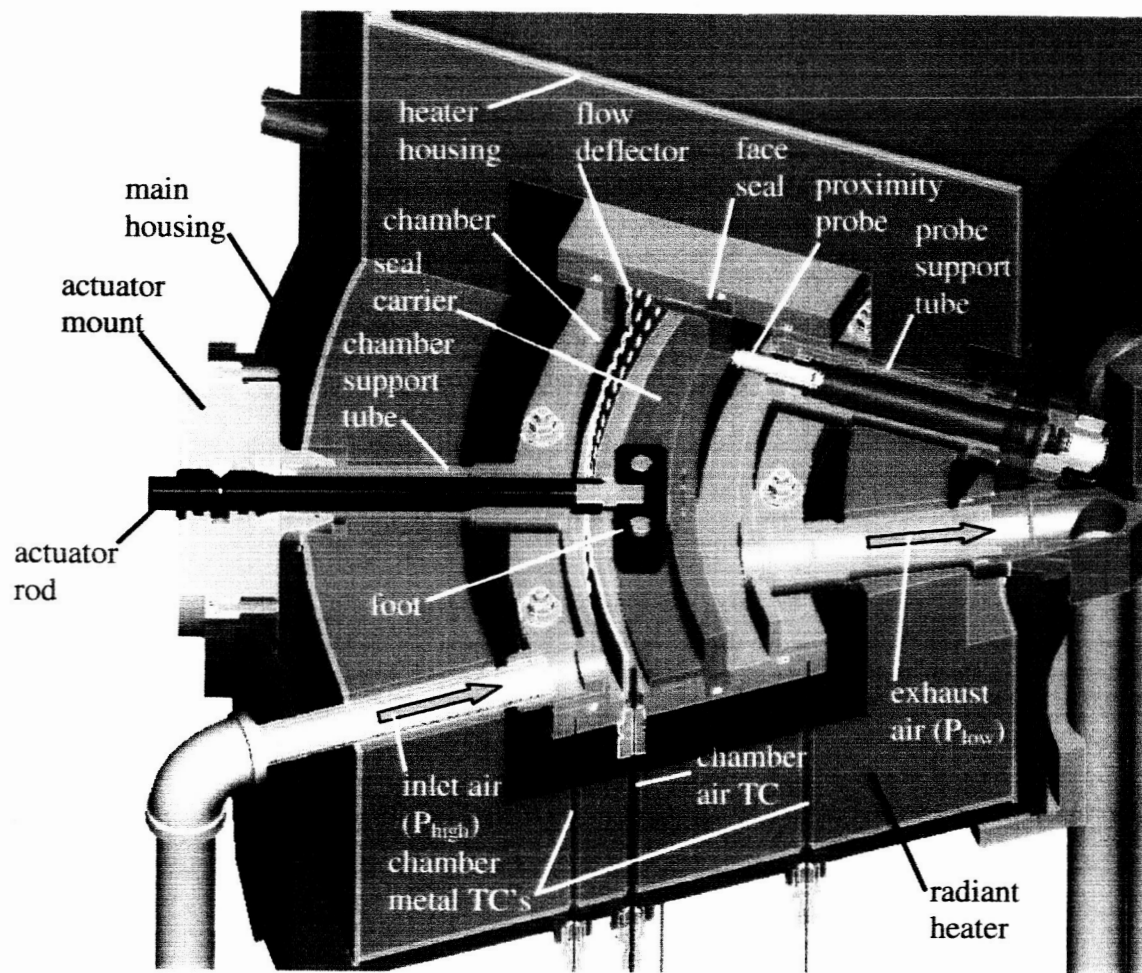
At the heart of the rig is a segmented shroud structure (seal carrier) that would structurally support the tip seal shroud segments in the engine. Radial movement of the seal carriers controls



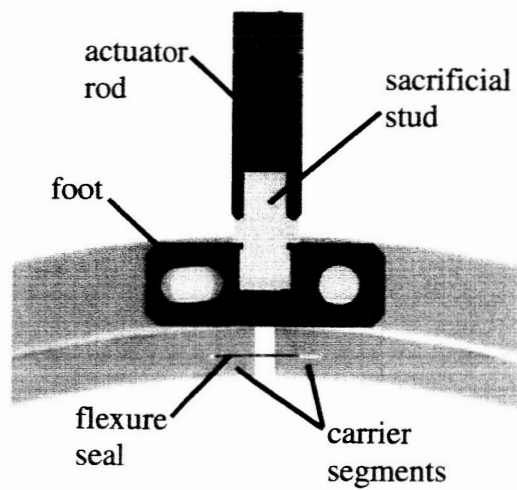
**Figure 1.** ACC Test Rig with Housing Lid and Chamber Cover Plate Removed

the effective position/diameter of the seal shroud segments, thereby controlling blade tip clearance. The carrier segments are connected to independent hydraulic actuators through an actuator rod assembly as shown in Figure 2. The foot of the actuator rod assembly positions the carrier segments in the radial direction, while allowing relative circumferential movement or dilation of the seal carrier segments through a pinned and slotted arrangement as shown in Figure 3.

The rig housing consists of two concentric cylinders, which form an annular cavity. An annular radiant heater made of upper and lower halves surrounds the segmented seal carrier structure to simulate the HPT tip seal backside temperature environment. A pressurized chamber encloses the carrier segments inside the annular heater through which heated pressurized air is supplied to simulate the cooling/purge air pressure on the seal backsides. Heated air enters the chamber via three pipes that are fed from a manifold at the air heater exhaust through radial inlet ports. The flow is directed circumferentially around the outer chamber wall by a flow deflector that has a series of radial holes positioned about its circumference except at the inlet positions. Air that escapes over and between the carrier segments is vented out of the rig through a number of exhaust pipes that protrude radially along the inner chamber wall. The number and inner diameter of exhaust pipes were chosen to eliminate the possibility of backpressure at the exhaust ports. The pressurized air is sealed along the sides of the seal carrier segments by contacting face seals that are energized via metal "E"-seals imbedded in the upper and lower chamber plates.



**Figure 2.** Rig Cutaway Detail



**Figure 3.** Actuator Rod Foot-Carrier Detail



The joints between adjoining carrier segments are sealed with thin metal flexures. A series of radial tubes projecting outward from the chamber's inner and outer side walls serve as supports, air supply and exhaust ports, probe fixtures, and the actuator rod guides. The chamber functions to support and align the carrier segments and actuator rods, as well as to house instrumentation and to seal the pressurized air from the radiant heater which is not designed to carry any pressure loading.

High temperature proximity probes measure the radial displacement of the seal carriers at various circumferential locations. These measurements provide direct feedback control to the independent actuators and allow the desired radial position (clearance) to be set. The direct feedback control system allows for simulation of realistic transient tip clearance changes in lieu of a rotating turbine wheel. Superimposing a mission-clearance-profile over the actual clearance measurement input to the actuator controllers will allow researchers to assess the system's response to the most dramatic transient events such as mechanical and thermal loading of the rotor during takeoff and re-accel.

#### *Milestones*

<b>Description</b>	<b>Date</b>	<b>Status</b>
1. Experimentally characterize Generation 1 regenerative-seal concept material	3Q FY03	Complete
2. Define control system requirements and architecture	3Q FY03	Complete
3. Perform feasibility studies of morphing structural concepts	4Q FY03	Complete

#### *Publications*

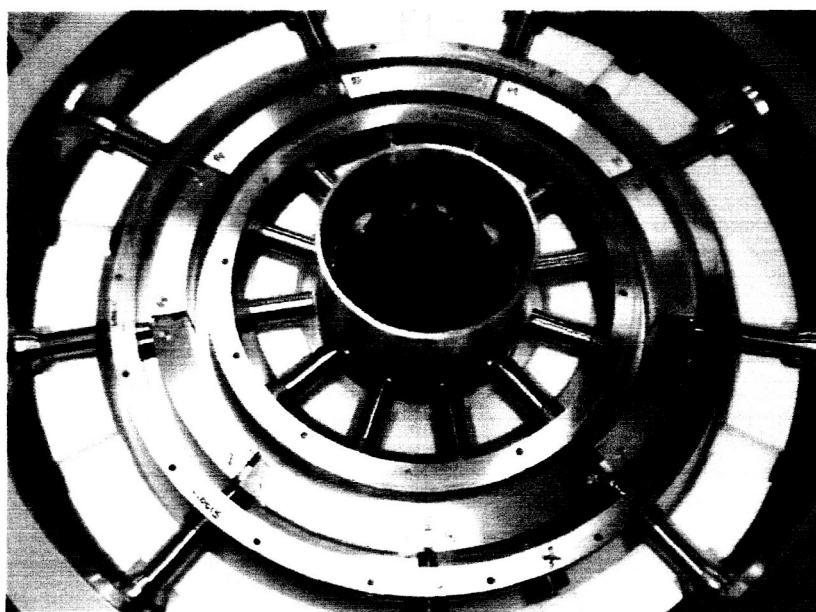
Dr. Lattime co-authored a review paper on the design of a first generation ACC system concept and a state-of-the-art test rig for evaluation of ACC system concepts. The paper, entitled "Test Rig for Evaluating Active Turbine Blade Tip Clearance Control Concepts", was presented at the 38th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit (Huntsville, AL) on July 22, 2003.

#### *Funding*

Dr. Lattime was a major contributor to a NASA led team to form a multidiscipline proposal entitled "Morphing Structures for Self-adaptive Propulsion". The proposal combined researchers from four different NASA GRC branches, spanning three divisions (Structures and Acoustics, Controls and Instrumentation, and Turbomachinery and Propulsion Systems). The 4-year, [REDACTED] proposal was awarded September, 2002 and was assigned a NASA Level-1 milestone by the Revolutionary Aero-propulsion Concept (RAC) program managers. Researchers were successful in obtaining their proposed first year budget of [REDACTED] in 2003.

**FY04**

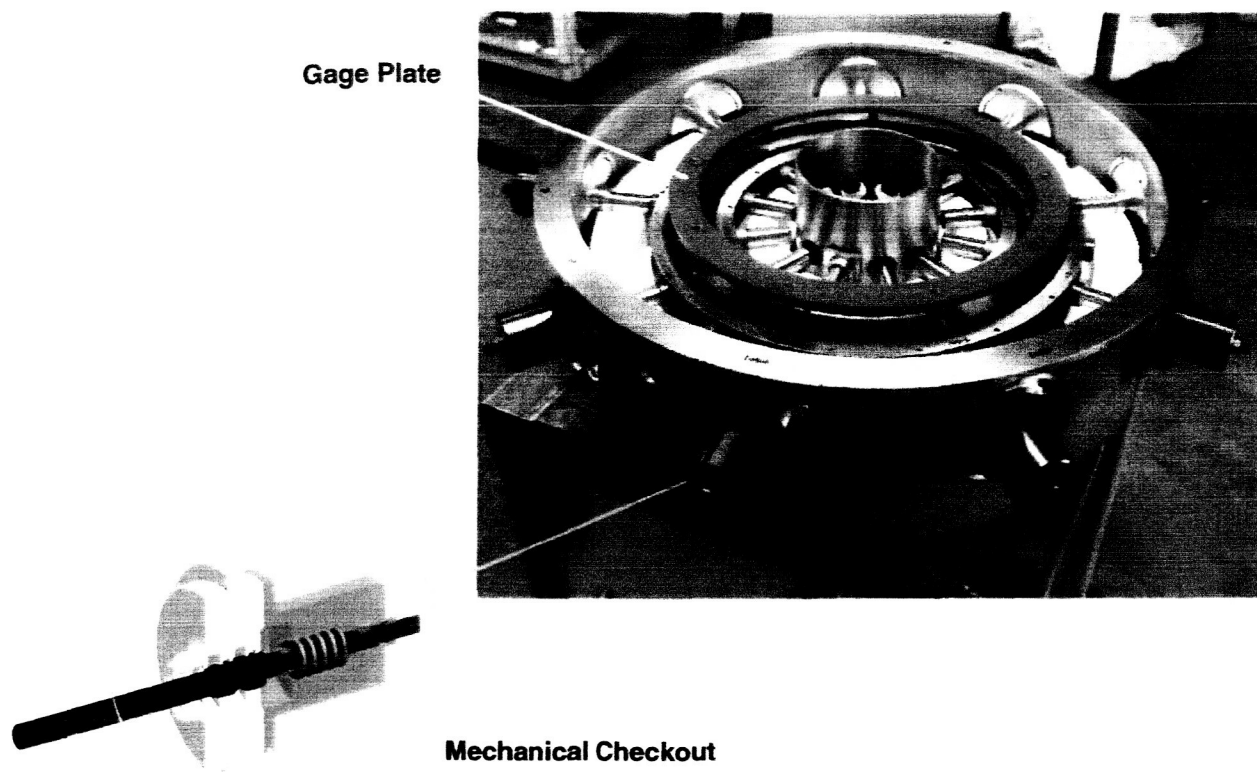
*Completed Fabrication of First Generation ACC System Concept and ACC Test Rig:* A mechanically actuated ACC system concept and test rig were designed and fabricated. The ACC rig assembly hardware is shown in Figures 4 and 5. Figure 4 shows the ACC Rig and shroud assembly. Figure 5 shows the ACC rig with the gage plate (used to align the shroud segments on their neutral diameter) and mechanical actuators (used to test the available stroke and alignment of the shroud and actuation linkages). The test rig has been fully assembled and is currently undergoing mechanical checkouts and a final hydro test of the pressure chamber before delivery to NASA GRC.



**Figure 4.** ACC Rig with shroud assembly

#### *Milestones*

<b>Description</b>	<b>Date</b>	<b>Status</b>
1. Complete fabrication of Active Clearance Control Test Rig	4Q FY04	Complete
2. Real-time analytic demo of clearance control system	4Q FY04	Complete
3. Evaluate growth of regenerative material with rib structure	4Q FY04	Complete



**Figure 5.** ACC Rig with gage plate and mechanical checkout devices

#### *Publications*

Dr. Lattime co-authored a review paper on the mechanisms behind tip clearance changes, concepts to manage tip clearance, and benefits of reducing tip clearance and tip seal wear for the HPT. The paper, entitled "Turbine Engine Clearance Control Systems: Current Practices and Future Directions", was published in the Journal of Propulsion and Power in March of 2004.<sup>5</sup>

Dr. Lattime co-authored a review paper on the design of a first generation ACC system concept and a state-of-the-art test rig for evaluation of ACC system concepts. The paper, entitled "Test Rig for Evaluating Active Turbine Blade Tip Clearance Control Concepts", was accepted for publication by the Journal of Propulsion and Power, in October of 2004.<sup>4</sup>

#### *Funding*

During the reorganization of NASA GRC's aero-propulsion programs in FY03, the "Morphing Structures for Self-adaptive Propulsion" task was transferred from the RAC program to the UEET program. The task's scope was reduced and focused specifically on development of a mechanical ACC system and test rig. Researchers were successful in obtaining \$530k of their proposed \$619k budget for 2004.

## References

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1. Lattime, S.B., Steinetz, B.M., "Turbine Engine Clearance Control Systems: Current Practices and Future Directions," NASA TM-2002-211794, September, 2002.
2. Bureau of Transportation Statistics, 400 7th Street, SW, Room 3103, Washington, DC 20590.
3. Rocky Mountain Institute (RMI), "Climate, Air Travel Emissions," 2002.
4. Lattime, S.B., Steinetz, B.M., "Test Rig for Evaluating Active Turbine Blade Tip Clearance Control Concepts," NASA TM-2003-212533, July, 2003, accepted for publication, *Journal of Propulsion and Power*, October, 2004).
5. Lattime, S.B., Steinetz, B.M., "High-Pressure-Turbine Clearance Control Systems: Current Practices and Future Directions," NASA TM-2002-211794, *Journal of Propulsion and Power*, Vol. 20, No. 2, March-April 2004, pp. 302-311.